ON THE RELATIONSHIP BETWEEN DP-1, DP-2, THE GROWTH AND EXPANSION PHASES OF SUBSTORMS, AND IONOSPHERIC ELECTRIC FIELDS

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The problem of understanding the physical conditions preceding and causing the explosive or expansion phase of substorms has been studied for several years. In its most recent form this problem concerns questions of the existence of a growth phase prior to the explosive phase of a substorm and whether, if it exists, the growth phase current systems are fundamentally different from those during the expansion phase. The purpose of the present letter is to show that the resolution of different views on these questions may be achieved through examination of ionospheric electric field data obtained during isolated substorms.

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The problem of understanding the physical conditions preceding and causing the explosive or expansion phase of substorms has been studied for several years. In its most recent form this problem concerns questions of the existence of a growth phase prior to the explosive phase of a substorm and whether, if it exists, the growth phase current systems are fundamentally different from those during the expansion phase. The purpose of the present letter is to show that the resolution of different views on these questions may be achieved through examination of ionospheric electric field data obtained during isolated substorms.

Through examination of ground magnetometer records, Nagata and Kokobun (1962), Nishida, Iwasaki, and Nagata (1966), and Obayashi (1967) identified two types of high latitude equivalent ionospheric current systems, called DP2 and DP1. The high latitude, nighttime, DP2 currents flow poleward while those of DP1 flow as an intense westward electrojet (Nishida, 1971). DP2 currents are thought to be assoicated with southward turning interplanetary magnetic fields and are established about 15 minutes after such reorientations of the interplanetary magnetic field. DP1 currents are associated with substorms and develop explosively about an hour after DP2 appears (Nishida, 1971).

Through studies of typical signatures in ground magnetometer data, McPherron (1970) has proposed the existence of a growth phase of substorms lasting about an hour before the westward auroral electrojet develops explosively during the expansion phase of the substorm. Thus McPherron's growth and expansion phases might be associated with Nishida's DP2 and DP1 respectively, except that the current systems of DP2 and DP1 are in different directions, while currents during the growth phase are thought by McPherron (1970) to be similar in direction but smaller in magnitude than those during

the expansion. Thus, two major questions have arisen:

1. Is there a growth or DP2 phase to substorms occurring before the expansion or DP1 phase?

2. If so, is the current system during this precursor phase similar to or different from that during the explosive phase of the substorm?

The concepts of growth, expansion, DP2, and DP1, have arisen largely from analyses of ground magnetometer data. While such analyses have produced an important body of knowledge on magnetospheric processes, they may not be able to uniquely answer questions such as those above because:

1. Determining when and how a magnetometer trace deviates from the zero level involves definition of the zero level. Many workers feel that conclusions on the existence of DP2 and the growth phase depend critically on this choice of zero level.

2. Since negative bays are known to propagate in space at speeds of ~1 kilometer/second, time delays between observation of similar phenomena at different sites are the order of tens of minutes. Many workers feel that what appears as a precursor to the main negative bay can be explained in terms of these propagation effects without invoking a growth phase or DP2.

3. Since both the amplitude and direction of the north-south component of the interplanetary magnetic field are constantly changing, it is sometimes difficult to associate a feature of the interplanetary magnetic field with a feature in the substorm. Some workers find relations and time scales different from those of Nishida.

4. Because magnetometer deflections at a series of ground sites cannot be used to deduce uniquely the current pattern that produced them,

because of the possible importance of parallel currents in determining ground magnetic variations, and because the Hall and Pederson conductivities vary greatly during a substorm, different workers arrive at different interpretations of essentially the same initial magnetometer data. An example of this fact is the different current systems proposed by Nishida (1971) for DP2 and McPherron (1970) for the growth phase.

One may avoid all of the above difficulties by focussing attention on the ionospheric electric field variations driving the currents before and after the explosive phase of isolated substorms. Analyses of electric field variations during 19 such substorms have given the idealized picture reproduced in Figure 1 and described below (Mozer, 1971). Within a fraction of an hour after the interplanetary magnetic field turns southward, a large scale westward component of the ionospheric electric field develops on nightside auroral zone magnetic field lines. This component appears simultaneously within about 15 minutes at different auroral zone sites (Mozer and Manka, 1971; Mozer, 1971) where the time uncertainty results largely from the presence of turbulent variations of the ionospheric electric field. This westward field causes an inward motion and thinning of the plasma sheet, the equatorward motion of auroral arcs, the development of a tail-like magnetic field geometry deeper in the nightside magnetosphere, and the flow of currents in the ionosphere and along magnetic field lines. After about an hour, the magnetosphere drifts into an unstable condition in which a large equatorward component of ionospheric electric field develops. In each of the 19 substorms for which electric field data is available, the equatorward component developed after the westward component and, in those cases for which data from more than one site were available, the equatorward

components appeared simultaneously within ~15 minutes at different sites (Mozer and Manka, 1971; Mozer, 1971). This equatorward component drives a westward Hall auroral electrojet current that signals DP1 or the expansion phase in ground magnetometers.

From the electric field data there are thus two phases of a substorm corresponding respectively to the westward electric field and the equatorward field. The ~1 hour time scale for the duration of the westward field before the explosion corresponds well with time scales of both DP2 and the growth phase. The equatorward electric field component drives currents in different directions during DP1 or the expansion phase then were driven by the westward field during the growth or DP2 phase. The effects of these currents on ground magnetometers depend on how the Pederson and Hall conductivities vary during the substorm and how the different current systems close in the ionosphere or magnetosphere. The conclusions from analyses of ionospheric electric field data are thus that:

1. There is a ~1 hour initial phase to substorms that is associated with westward electric fields and the $\bar{E} \times \bar{B}$ drift of the magnetosphere into an unstable configuration. This interval of westward electric field probably corresponds to Nishida's DP2 or McPherron's growth phase.

2. The expansion or DP1 phase of substorms is associated with the development of an equatorward component of electric field in the nighttime magnetosphere. This field component combines with precipitation induced changes in the Hall and Pederson conductivities to change the previously existing current system. Since the ionospheric currents flowing before and after the appearance of the equatorward electric field component probably close by parallel currents having

different geometries (Mozer, 1971), there is a reorientation of the magnetospheric current system at the onset of the expansion phase. The details of this reorientation and its effects on ground magnetometers require further study.

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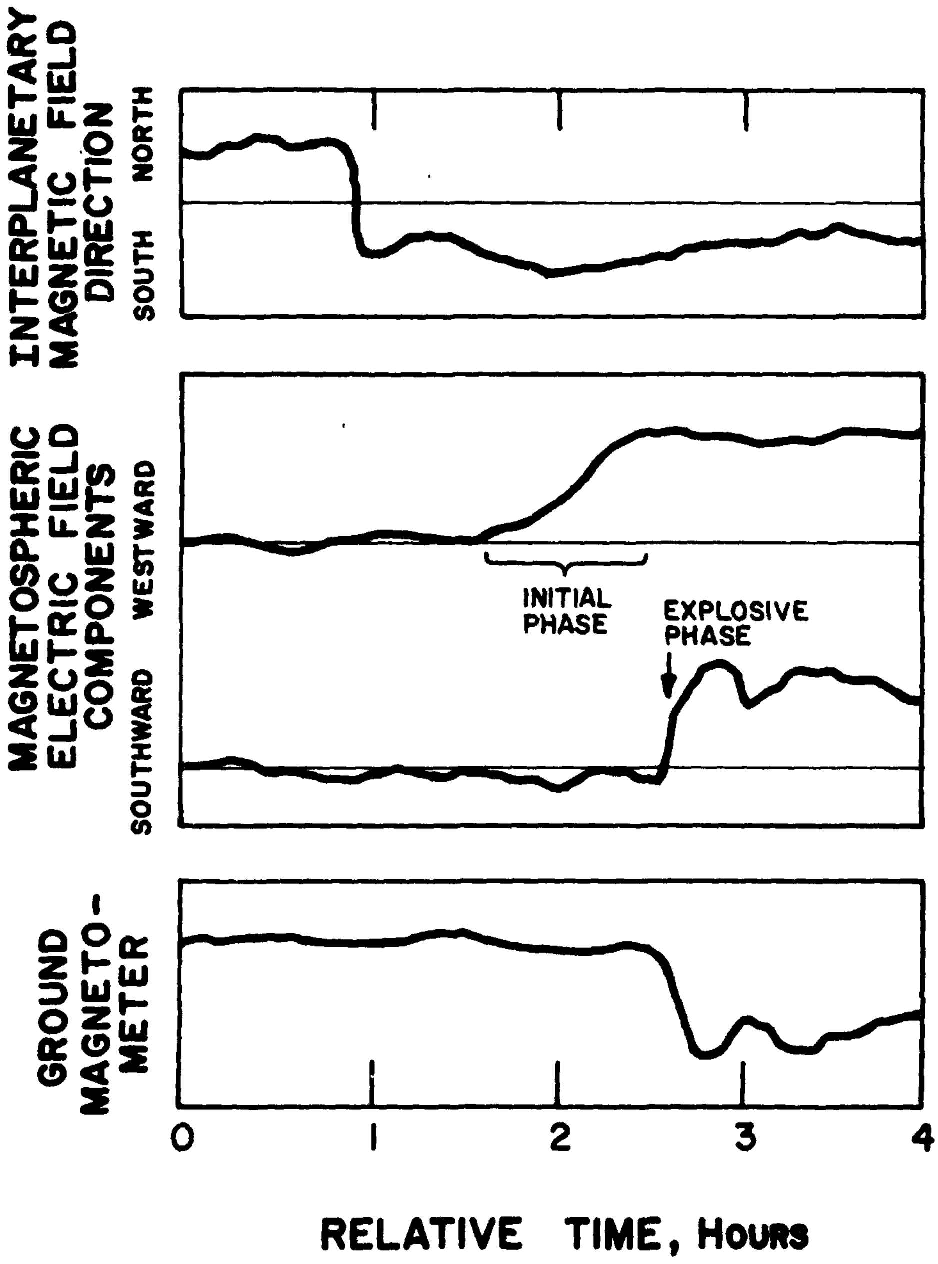

Figure 1 An idealized description of ionospheric electric field variations during an isolated magnetospheric substorm.